Research Article

Preliminary Evaluation of Quality and Rank of Banik Coal, Zakho, Duhok Governorate, Kurdistan Region, Iraq

Govand H. Sherwani *

*Department of Civil Engineering, College of Engineering, Cihan University-Erbil, Erbil, KRI, Iraq
E-mail: govand.sherwani@cihanuniversity.edu.iq

Access this article online		
Received on: July 6, 2021	**Accepted on:** September 6, 2021	**Published on:** December 31, 2021
DOI: 10.25079/ukhjse.v5n2y2021.pp36-46	**E-ISSN:** 2520-7792	

Abstract
This study aims to evaluate the rank (or grade) and economic value of the so–called coal horizon/bed outcropping in the vicinity of Banik and Shiranish-Islam villages of Zakho District, Duhok Governorate, Iraq. These coal-like beds (locally known as Banik Coal) make up few meters within the upper part of the Jurassic Naokelekan Formation. The evaluation was mainly based on standard chemical tests of coal (proximate and ultimate analyses) achieved in foreign and local laboratories. The test results were assessed according to the standard coal tests introduced by the American Society for Testing and Materials (ASTM).
The latest stratigraphic studies revealed that the presumable coal horizon was thin beds of limestone and dolomitic limestone alternated with frequent shales all intensively impregnated with bituminous materials, mostly of hydrocarbon source. The bituminous beds were observed in both upper and lower parts of Naokelekan Formation. The standard proximate coal analysis has shown low percent of fixed carbon and high percent of volatiles and ash which support the hydrocarbon source of these bituminous beds. The high values of mineral matter display the dominance of minerals rather than the carbon in the local samples. Consequently, it would be difficult to classify these bituminous beds similarly to the standard coal ranks of ASTM. However, the Gross Calorific Value (heating value) of these beds would imply that they can be used as relatively poor quality source of fuel. Besides, the exploitation of Banik coals would be influenced by the cost of extraction (or mining), the expected prices of produced coal, and the prices of alternative sources of energy.

Keywords: Banik Coal, Duhok, Kurdistan Region, Naokelekan, Shiranish.

1. Introduction
1.1. Preface
By the early 1950s, and possibly earlier, the pioneer geologists of Iraq Petroleum Company (IPC) had launched programs of geologic survey of wide areas over Northern Iraq. Their efforts were originally stimulated by earlier discoveries and production of huge Tertiary oil accumulation in Kirkuk and other oil fields. Consequently, many geologic formations were named and given formal description for the first time. These newly described formations included some older units of the Triassic and Jurassic Periods, followed by others belonging to the Paleozoic Era.

The first stratigraphic description of the Jurassic Naokelekan Formation was presented by Morton and Wetzel (1950 in Bellen *et al.,* 1959), from a village called Naokelekan, located in the Imbricated Zone of Iraq, in the vicinity of Rawanduz town (Figure 1). The description of that section indicated the presence of the so-called Coal Horizon in its lower part of the Naokelekan Formation. That stratigraphic description, with further details, were presented with further geologic information by Jassim and Buday (2006).

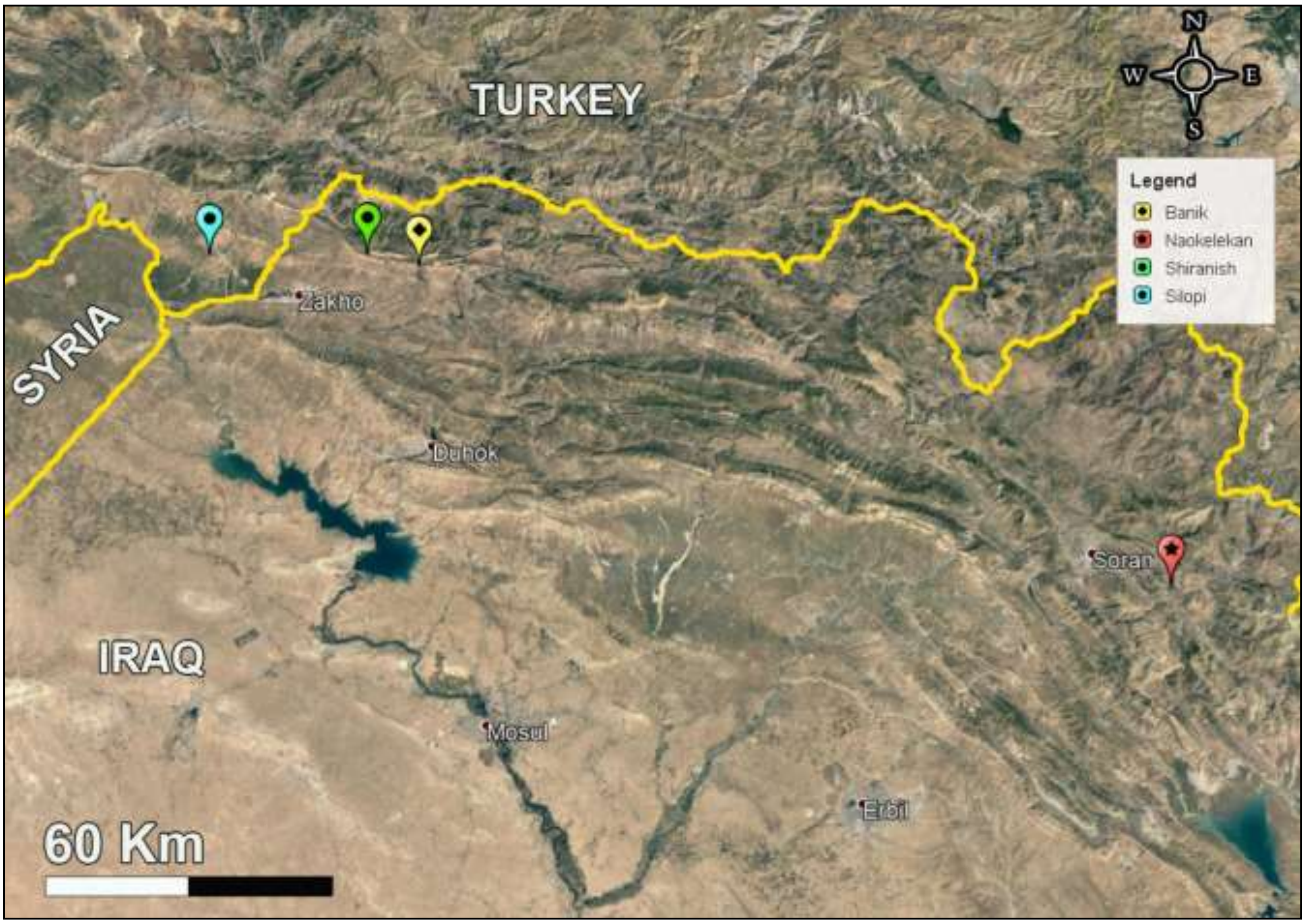


Figure 1. Satellite image showing the location of the studied sections.

For several decades, exploration activities and plans for Northern Iraq had focused on seeking for hydrocarbons in areas away from the Imbricated and Thrust Zones that were believed to have poor petroleum potential. Consequently, little attention was paid to these presumed coal beds of the Naokelekan Formation.

1.2. Aim of the Study

The present study aims to highlight some of the geological and chemical aspects of the so-called Coal Horizons (or beds) described in the lower part of Naokelekan Formation. The current prospect attempts to offer the reply of questions such as:

- Are these beds real coal? If so, what is their grade or rank ?
- Have they any economic value or benefit to make a new source of energy ?

1.3. Study Area

In the present study, two locations/sections of the Naokelekan Formation, were selected. These locations involve outcrops of this formation near Banik village (locally known as Banik Haji Ghazi) and Shiranish-Islam village in Zakho District, Duhok Governorate, Iraqi Kurdistan Region (Figure 1). Once the Tectonic Subdivision of Iraq is considered, the study area of both sections lie in the Imbricated Zone of Northern Iraq (Fouad, 2015). The selection of these two sites was intended to facilitate comparison between the results of the lab tests of local samples with those of a samples in the vicinity of Silopi, the closest Turkish town.

2. Geologic Setting

2.1. Naokelekan Formation

The first stratigraphic description of the Jurassic Naokelekan Formation, presented by Morton and Wetzel (1950 in Bellen *et al.,* 1959), is briefed in a columnar section (Figure 2) which demonstrates several lithologies, with total thickness of 14m. This section displays that the lower and the upper parts, either the shale or carbonate fraction are dominantly bituminous. The middle part of the Naokelekan Formation (called Mottled Bed) is fossiliferous dolomitic limestone with traces of ammonites.

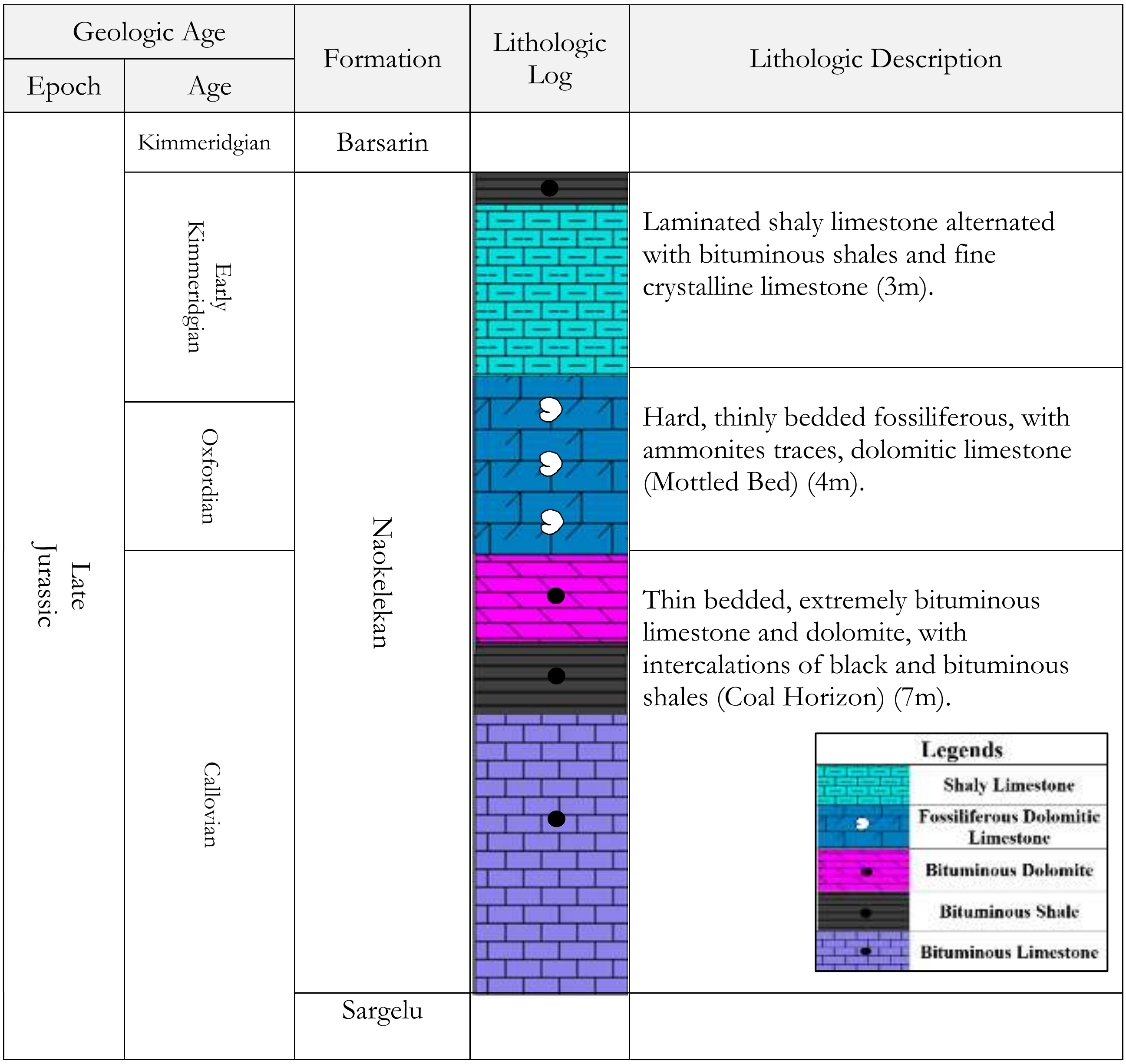


Figure 2. A Stratigraphic column manifesting the first formal description of Naokelekan Formation in its type section at Naokelekan Village, Erbil. (outlined from Morton and Wetzel 1950 in Bellen *et al*., 1959)
No vertical Scale. The whole section is 14 m.

The lower unit of the Naokelekan Formation is composed of thin bedded, extremely bituminous limestone and dolomite, with beds of black bituminous shales. Influenced by its distinctive black color, the earlier geologic texts had referred to the lower unit as Coal Horizon, which was an informal field nomenclature.

The text prepared by Jassim and Goff (2006) stands as a comprehensive display concerning all disciplines of Geology of Iraq. That text added outlines of depositional environment and the sedimentary cycles of all Jurassic rock units, including the Naokelekan Formation. Salae (2001), in a post-graduate dissertation, contributed to depositional environment and diagenetic events of the Naokelekan Formation. Balaky (2015), in a sequence stratigraphic approach, believed that the Naokelekan Formation can be divided into two third-order sequences, the upper and lower parts of the Naokelekan Formation belong to two HST (Highstand Systems Tract), separated by a TST (Transgressive Systems Tract) in the middle. Later, Abdula (2016) contributed to stratigraphy of the Naokelekan Formation and believed that its age in Iraqi Kurdistan is Callovian-Upper Oxfordian. Recently, Al-Atroshi *et al.* (2019) and Abdula *et al.* (2020)

assessed the type and thermal maturity of organic matter, and the petroleum generation potential of the Naokelekan Formation, across the Kurdistan Region of Iraq, by applying organic petrographic methods and Rock Eval Pyrolysis.

2.2. Organic Matter in the Naokelekan Formation

The organic matter of the Naokelekan Formation was recognized as Types II and III kerogen (Othman, 1990; Al-Atroshi *et al.,* 2019), or Types III and IV (Abdula *et al.,* 2020). This kerogen was described as mature and within the oil generation window in Sargelu locality (Baban and Ahmed, 2014). Salae (2001) believed that the dark colored rocks of the Naokelekan Formation are due to kerogenous rather than bituminous material as was reported earlier by Bellen *et al.* (1959). Whereas Abdula (2016) stated that these rocks seem to be a mixture of kerogen and bitumen.

Salae (2001) and Balaky (2015) agreed that the succession of the Naokelekan Formation bears no evidences of the existence of real coal, and that the presumed coal horizon is absent and replaced by argillaceous limestone in Hanjera and Barsarin sections. Whereas, Abdula (2018) argued that the coal horizon/bed is existing in Barsarin section. Al-Badri (2012), in a different perspective, stated that the lower part of the formation at Banik section (only 7m thick), is composed of alternating calcareous siltstone and shale, dark grey to black brittle coal and coaly calcareous mudstone, overlain by 4m-thick, brittle, and dark carbonaceous calcareous mud rock and dolosiltite.

In some cases, where bituminous material is filling the fractured sedimentary rock, the emplacement of bitumen into the fractures occurs under high pressure causing brecciation and impregnation (Parnell *et al.,* 1998). The sequence stratigraphic setting exposed by Balaky (2015), placing the upper part of the Naokelekan Formations as HST, would secure a suitable condition for impregnation of bitumen in the limestone and dolomite strata. The evaluation of organic matter presented by Abdula *et al.* (2020) implied that the bitumen in the Naokelekan Formation is mainly migrated (migra-bitumen) and partly formed through heating (pyro-bitumen) of ancestor organic matter during maturation stages.

As for the current case, it is believed that bitumen injection into the Naokelekan Formation followed fracturing of deeply seated hydrocarbon reservoir that received hydrocarbon from early Jurassic or older source rocks.

2.3. Coal Occurrence in the neighboring Countries

2.3.1. Iran

The black coal deposits of Iran refer to Jurassic age in the Alborz area, with some Tertiary Lignite of Khorasan area. The Alborz Jurassic coal is bituminous with high ash and sulphur content (Thomas, 2002). These coals are utilized for local need of energy and limited metallurgical industries. Considering the geologic age and the geographic location, the bituminous coal of Alborz is likely correlatable with the Iraqi Banik coal that is included within the Jurassic Naokelekan Formation.

2.3.2. Turkey

Considerable coal deposits are found in Carboniferous and Tertiary rocks of Turkey. The Carboniferous coals (Zonguldak coalfields) are found in the north and are of bituminous type with low ash and sulphur. The Tertiary Lignite coals are found in western and central Turkey (Thomas, 2002). The largest open-cast coal mine of Turkey is Afsin-Elbistan mine (central Turkey) where Pliocene deposits are targeted for Lignite.

3. Methodology

The current prospect included site investigation of the Naokelekan Formation and its bituminous (coal-like) beds, particularly in the vicinity of Banik and Shiranish villages (Figure 1), near Zakho town, Iraqi Kurdistan Region. This was followed by collecting fresh representative rock samples of the highly bituminous beds (Coal Horizon). Later, the coal samples were tested through the standard coal tests of American Society for Testing and Materials (ASTM): (Proximate Analysis - D3172-13, and Ultimate Analysis D3176-15) in chemical labs in a local university and abroad. The evaluation of mineral content, rather than carbon, in the analysed samples were performed via mathematical calculation of a newly introduced coal quality parameter called Mineral Matter (MM) (Thomas, 2002). The study terminates with evaluation of coal properties and rank (or grade) of the local samples through comparing the percent of their chemical components and properties with the standard tables of coal ranks. The comparison was additionally visualized by explanatory charts.

4. Results and Discussion

4.1. Standard Coal Analysis

The analysis of coal has a decisive role in designating the rank (or grade) of coal, hence, its economic value as a source for energy. The common analytical approaches for coal are based on either the British Standards (BIS) or the American Standards (ASTM D3172-13 and ASTM D3176-15). It is imperative to understand that all these analyses would clarify how the different chemical components of coal (moisture, ash, volatile, and fixed carbon) are related to each other and how they change among the various coal ranks (Thomas, 2012). Out of all analytical systems, two standard sets of analyses are performed:

4.1.1. **Proximate Analysis (ASTM Standards D3172-13)**

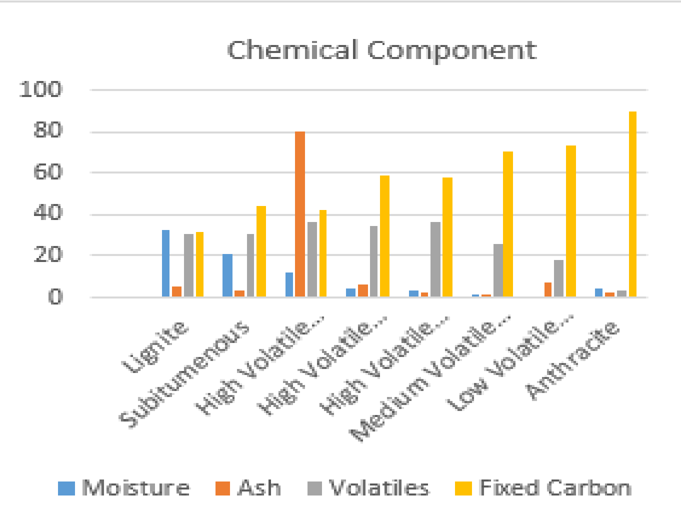
This is the first standard test performed on coals (or coal-like samples), and is intended to identify the quantity (percent) of the main chemical components (Moisture, Ash, Volatiles, and Fixed Carbon) of a coal sample. The most reliable Proximate Analysis Table is that presented by ASTM (Table 1). Most of specialized labs would add the calculated heat (or calorific) value to the table of Proximate Analysis.

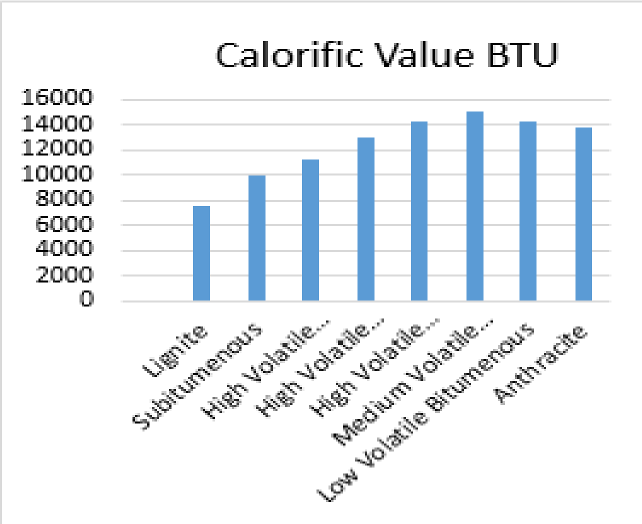
4.1.2. Ultimate Analysis (ASTM Standards D3176-15)

This analysis is considered as the final test on the coal samples. It is performed to determine the percentage of Carbon and Hydrogen released in form of gaseous products after complete combustion of coal (Thomas, 2002). It also determines of the remaining Sulphur, and Nitrogen. In the Ultimate Analysis, the percentage of Oxygen, which is a component of many organic and inorganic compounds in coal, is estimated as well (Table 2). This test is recommended, once the results of Proximate Analysis were encouraging and indicative to rich coal bearing strata.

Table 1. Standard Proximate Analysis of coal (ASTM standards D3172-13).
The two charts below display the increase of Carbon Percent and Calorific Values, starting from Lignite (lowest grade) to Anthracite (highest grade).

Coal Rank (Coal Grade)	Moisture %	Ash %	Volatiles %	Fixed Carbon %	Calorific Value BTU/lb	Calorific Value cal/gm
Lignite	32.5	5.0	30.8	31.7	7626	4237
Sub-Bituminous	20.7	3.9	30.7	44.7	10029	5572
High Volatile Bituminous– C	11.9	8.5	36.9	42.7	11282	6268
High Volatile Bituminous- B	4.2	6.4	34.6	58.8	13105	7281
High Volatile Bituminous- A	3.0	2.4	36.3	58.3	14326	7959
Medium Volatile Bituminous	1.4	1.8	26.0	70.8	15091	8384
Low Volatile Bituminous	0.6	7.4	18.2	73.8	14380	7989
Anthracite	4.2	2.4	3.1	90.3	13791	7662





4.2. Analysis of Local Coal Samples

The main Proximate Analysis of samples from the coal horizon of the Naokelekan Formation was executed in a specialized lab in Turkey (Table 3). This table displays the main chemical contents of the samples. An extra test, to estimate the Gross Calorific Value (GCV) and effect of sample dryness, was conducted in the Labs of Department of Chemistry, College of Science, Salahaddin University, Erbil (Table 4).

Table 2. Standard Ultimate Analysis of coal (ASTM standards D3176-15)
The chart below displays that the element carbon increases with the increase in coal grade (from Lignite to Anthracite).

Coal Rank (Coal Grade)	C %	H %	N %	S %	O %
Lignite	72.4	5.3	1.1	0.7	20.5
Sub-Bituminous	77.7	5.2	1.6	0.5	15.0
High Volatile Bituminous–C	79.2	5.9	1.5	2.9	10.5
High Volatile Bituminous-B	82.4	5.7	1.5	1.6	8.8
High Volatile Bituminous-A	85.0	5.7	1.6	0.8	6.9
Medium Volatile Bituminous	89.5	4.9	4.9	1.7	3.5
Low Volatile Bituminous	91.4	4.6	1.2	0.7	2.1
Anthracite	94.9	1.8	1.7	0.8	1.8

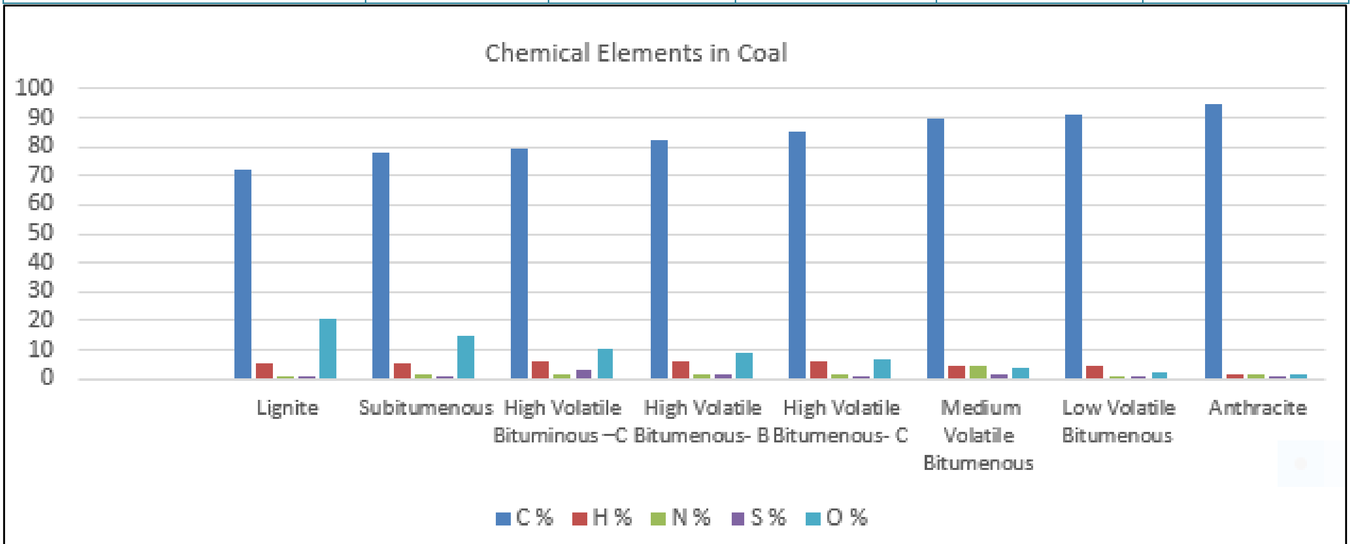


Table 3. Proximate Analysis of Coal samples from the Naokelekan Formation, in Banik and Shiranish sections, compared with one sample from Silopi section, Turkey

Section – Sample No	Moisture %	Ash %	Volatile %	Fixed Carbon %
Banik – 1	0.4	54.7	35.5	9.4
Shiranish - 1	0.4	50.5	39.8	9.3
Shiranish - 2	6.2	37.7	46.2	9.9
Shiranish - 3	0.6	44.6	45.9	8.9
Silopi	0.9	30.9	56.7	11.5

Table 4. Standard Proximate Analysis of Naokelekan coal samples – Shiranish site, executed at the Chemistry Labs of Salahaddin University, Erbil.

Samples	Moisture %	Ash %	Volatile %	Fixed Carbon %	Gross Calorific Value (GCV)	
					BTU / lb	cal / gm
Shiranish Sample	0.45	45.80	41.90	11.85	4194 - 4478	2330 – 2488
					average: 4336	average : 2409
Dry Sample	-	46.02	42.07	11.91	4498 - 6217	2343 – 2499
					average: 5357	average: 2921
Sulfur (S) %	in Original Sample		1.96 %			
	in the Ash		0.92 %			
	Total Sulfur		2.88 %			

4.3. Assessment of Analysis Results

4.3.1. Moisture Content

The moisture content is well considered in the coal industry, as it increases with decreasing rank of the coal (Thomas, 2002). Practically, the high moisture content is not desirable because it would consume some of the heat (calories) during burning and adds extra weight during transport (Thomas, 2002). However, the moisture content in the tested samples of Banik coal (Table 3) is extremely low and ranges between 0.4 to 0.9 %, with one anomalous figure in the sample of Shiranish-2. Drying coal samples results in increase of Gross Calorific Values for 21% (using cal/gm units) and 23% (using BTU units) (Table 4).

4.3.2. Ash Content

This component refers to the inorganic ingredients left post combustion of coal**.** The ash percent does not indicate the whole mineral matter in the coal, but those remained after losing volatiles (CO_2, SO_2, and H_2O) that are derived from carbonates, sulphides and clays (Nicholls, 1968). In a similar manner to moisture content, the high ash content would reduce calorific value of the coal. The favorite percent of ash for general usages would be around 20% (Thomas, 2002), whereas in the local samples, the average is around 50%, which is high and clearly and indicates the dominance of carbonate matters (Table 3). However, the sample from Silopi, Turkey has 30.9% Ash, which is still high (Table 3).

4.3.3. Volatile Percent

The amount of volatiles refers to gaseous constituent of coal that is released after air-free burning of coal at high temperature (Farhaduzzaman *et al.,* 2015). It belongs to mainly organic matter with lesser mineral content (Thomas, 2002). The recommended range of volatiles in coal or coal-like rocks is 20-40% (Thomas, 2002). Whereas, in the selected samples, at Shiranish and Banik sites, their values were slightly above and below this range (Tables 3 and 4), as they were between 35 and 46%, which makes no obstacle for domestic and most of industrial usages.

4.3.4. Fixed carbon

Fixed carbon refers to the percent of remaining carbon in the residue left after complete burning of coal. It is calculated by subtracting the volatile, moisture, and ash from the total percentage of 100% (Thomas, 2002). In the studied samples, the fixed carbon percent was notably low (8.9 - 9.9%) (Table 3). T he selected sample from the neighboring Turkish location (Silopi) had similar score of (11.9%). These figures are similar to those obtained from the test performed at Salahaddin University, Erbil (about 11.85 – 11.91 %) (Table 4). However, in the standard table of ASTM Standards (D3172-13), the lowest grade of coal (Lignite), shows over 30% of fixed carbon (Table 1).

4.3.5. Calorific Value (CV) of Coal

The Gross Calorific Value (GCV) is an important parameter that refers to the amount of heat for mass unit of coal after complete burning. The GCV is often called heating value or specific energy in some countries (Thomas, 2002). The calorific values of the dry sample from the Naokelekan Formation (Table 4) were determined through lab process at Salahaddin University-Erbil, as 4498 – 6217 BTU/lb (or 2343 – 2499 cal/gm). These samples would be considered within the range of Brown Coal – Peat according to tables introduced by Nicholls (1968). Whereas the ASTM standard tables (Table 1) would suggest a rank below Lignite which is the lowest coal rank. Since, the values of the significant parameters of Proximate Analysis (Fixed Carbon and Gross Calorific Value) were notably low (Table 3); as compared to all standard coal ranks listed at ASTM (Table 1), hence the local samples would not indicate any rich coal-bearing rocks. Therefore, the Ultimate Analysis was not recommended for the samples of Banik coal.

4.4. Mineral Matter (MM) in Coals

In many coals or coal-like deposits, the issue of mineral content or mineral matter (MM) and its calculation were concerned for industry institutes and researchers (Vorres, 1986). Several formulae were established aiming the calculation of MM. One of the latest, possibly with figures very similar to experimentally estimated ones, was introduced by Saini *et al.* (2015); as follow:

Mineral Matter (MM) = 0.74 (Moisture %) + 1.17 (Ash %)

Using this formula, the MM values of the standards coal ranks would count for less than 6 (in Anthracite) to less than 30 (in Lignite) (Table 5). It is obvious that the contribution of mineral matter is reversely related to carbon content. Whereas, the calculated MM for the local coal-like rocks (shown in Table 6), ranged from 36.81 (in the sample of Silopi) to 64.29 (in sample from Banik). The high MM in local samples is expected with their low carbon percent (Table 6).

Table 5. Mineral Matter (MM) in Standard Coal Ranks (using formula of Saini *et al.*, 2015).
The chart below displays that Mineral Matter is reversely related to carbon content in the different coal grades.

Coal Rank (Coal Grade)	Moisture (%)	Ash (%)	Fixed Carbon (%)	Mineral Matter (0.74 Moist + 1.17 Ash)
Lignite	32.5	5.0	31.7	29.9
Sub-bituminous	20.7	3.9	44.7	19.9
H.V. Bituminous –C	11.9	8.5	42.7	18.8
H.V. Bituminous- B	4.2	6.4	58.8	10.6
H.V. Bituminous- A	3.0	2.4	58.3	5.0
M.V. Bituminous	1.4	1.8	70.8	3.1
L.V. Bituminous	0.6	7.4	73.8	9.1
Anthracite	4.2	2.4	90.3	5.9

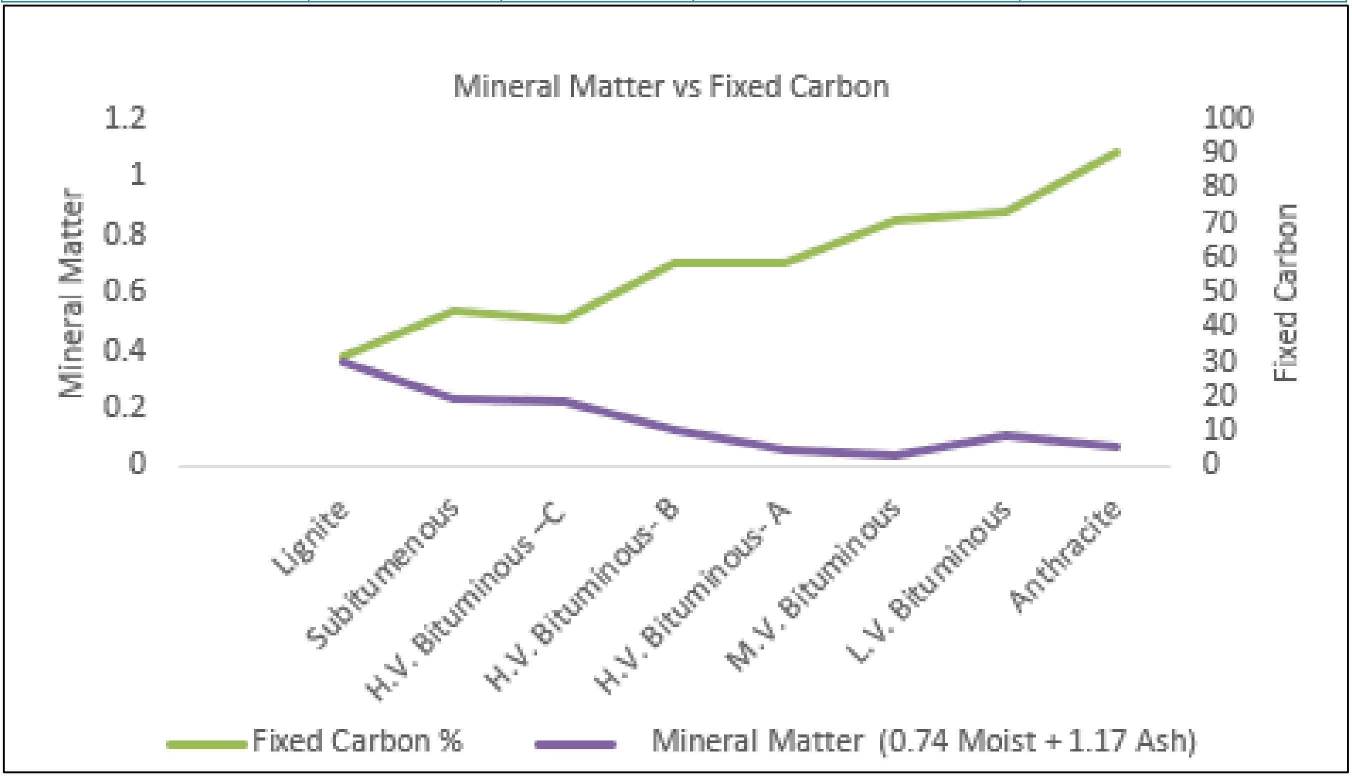
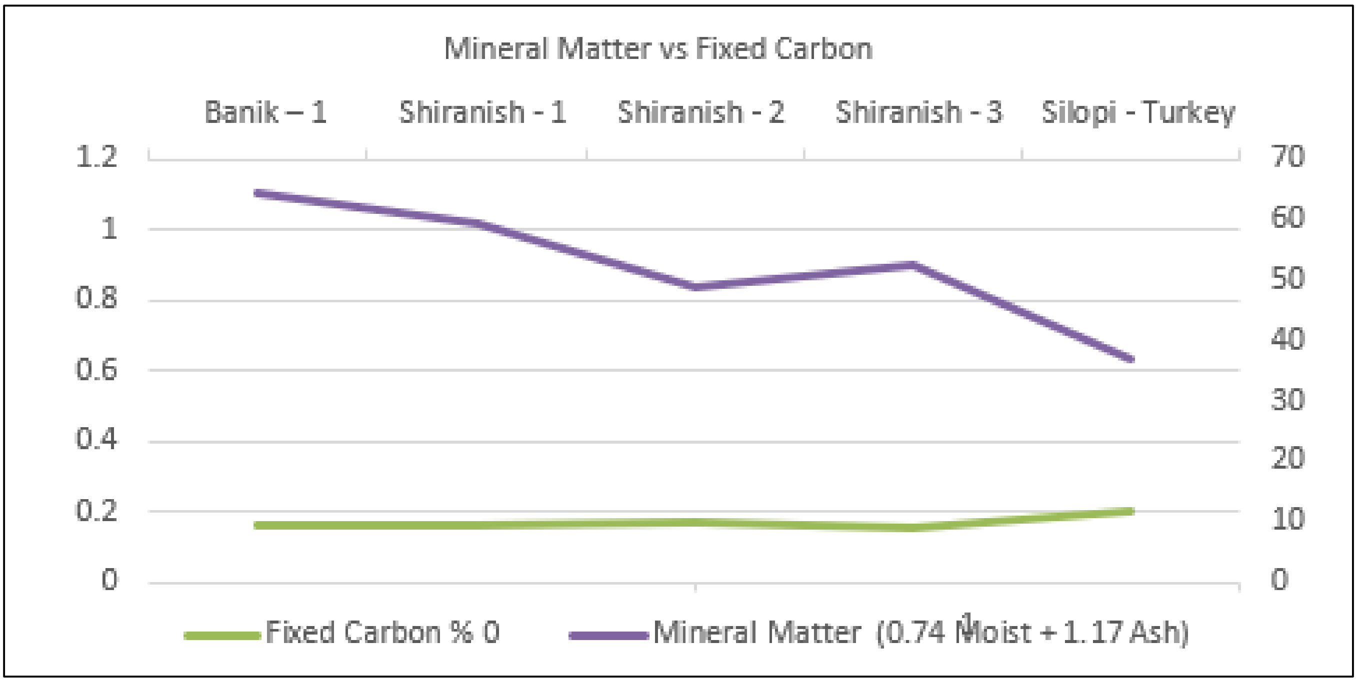


Table 6. Mineral Matter (MM) in Coal Samples (using the formula of Saini *et al*., 2015).
The chart below displays that Mineral Matter is reversely related to carbon content in the different coal samples.

Local Coal Samples	Moisture (%)	Ash (%)	Fixed Carbon (%)	Mineral Matter (0.74 Moist + 1.17 Ash)
Banik – 1	0.4	54.7	9.4	29.9
Shiranish - 1	0.4	50.5	9.3	19.9
Shiranish - 2	6.2	37.7	9.9	18.8
Shiranish - 3	0.6	44.6	8.9	10.6
Silopi - Turkey	0.9	30.9	11.5	5.0



5. Conclusions

The following conclusions were reached by the present study:
1-The previous studies related to the so-called Coal Horizon in the lower part of the Naokelekan Formation referred to different terminologies such as; bitumen (migra-bitumen, pyro-bitumen), kerogen, mixture of bitumen and kerogen. These debatable components were awarded to different petrology/rock terms; bituminous carbonates (limestone and dolomite), black shale, black coal, and coaly mudstone. Some researchers also argued about the location and/or the presence of the coal horizon within the section of the Naokelekan Formation. The current study, skipping all these arguments, has focused on the chemical assessment of the concerned coal horizon using standard coal tests of ASTM.
2- The Standard Proximate Analysis of tested coal samples has displayed low fixed carbon (less than 10%), low calorific value (average: 4336-5357 BTU), and high ash content (44-54 %) indicating properties below the lowest coal rank (Lignite). These values resemble those of very poor coal types (Peat or Brown Coal).
3- The values of the main components of Proximate Analysis impose limitation on using Banik coal as an alternative source for energy, particularly when the cost of this presumed coal is compared with the rather cheap hydrocarbons (Natural Gas and Petroleum) in local energy markets.
4-The calculated Mineral Matter (MM), a new parameter for coal assessment, displayed high values (52-64 %) which are much higher than values of MM of all traditional coal ranks (5-29 %). This reflects the dominance of minerals (mainly from carbonates) associated with low carbon content.
5-The newly exposed quantitative chemical criteria (Proximate Analysis) for samples from the Coal Horizon of the Naokelekan Formation, suggest that this term should be replaced by a more realistic alternative term, such as Coal-Like

Horizon. The concerned horizon resembles normal coal in appearance not in the content and heating value. Nevertheless, further studies, covering broad standard testing of samples in other sections of the Naokelekan Formation is highly recommended. This can be extrapolated to many other bitumen-rich rocks, as bitumen may have significant role even in the traditional coal grades or ranks.

Acknowledgment

The author expresses his gratitude to Ministry of Natural Resources-KRG and the former Kurdistan Geological Society for facilitating some of the tests in external labs in Turkey and Salahaddin University, Erbil, Iraq. Thanks are extended to Mr. Varoujan Sissakian from the University of Kurdistan Hewler (UKH) for reviewing the manuscript.

References

Abdula, R.A. (2016). Stratigraphy and Lithology of Naokelekan Formation in Iraqi Kurdistan-Review. *The International Journal of Engineering and Science (IJES), 5*(8), 07-17.

Abdula, R.A. (2018). *Organic petrography, mineralogy and rock-eval pyrolysis of Naokelekan Formation and generation history in the Upper Triassic-Jurassic sequences in Kurdistan Region, Iraq.* PhD thesis, Soran University, Soran, Iraq. pp. 243.

Abdula, R.A., Kolo, K., Damoulianou, M., Raftopoulou, V., Khanaqa, P. & Kalaitzidis, S. (2020). Rock-Eval analysis and organic Petrographical characterization of the Upper Jurassic Naokelekan Formation, Northern Mesopotamian Basin, Kurdistan Region-Iraq. *Bulletin of the Geological Society of Greece, 56*, 187-203.

Al-Atroshi, S.J., Sherwani, G.H. & Al-Naqshbandi, S.F. (2019). Assessment of the hydrocarbon potentiality of the Late Jurassic formations of NW Iraq: A case study based on TOC and Rock-Eval pyrolysis in selected oil-wells. *Open Geosciences* 2019; 11: 918-928.

Al-Badry, A.M.S. (2012). *Stratigraphy and geochemistry of Jurassic formations in selected sections – North Iraq.* PhD dissertation, Science College, University of Baghdad, Baghdad, Iraq. pp. 183.

ASTM (2013). ASTM D3176-15 : *Standard Practice for Ultimate Analysis of Coal and Coke.* https://www.astm.org/d3176-15.html

ASTM (2015). ASTM D3172-13 : *Standard Practice for Proximate Analysis of Coal and Coke.* https://www.astm.org/d3172-13.html

Baban, D.H. & Ahmed, S.M. (2014). Vitrinite reflectance as a tool for determining level of thermal maturity for the Upper Jurassic Naokelekan and Barsarin formations in Sargelu location, Kurdistan Region, NE Iraq: *Arabian Journal of Geosciences*, *7*(6), 2269-2277.

Balaky, S.M. (2015). Sequence stratigraphic analyses of Naokelekan Formation (Late Jurassic), Barsarin area, Kurdistan Region- Northern Iraq. *Arabian Journal of Geosciences*, 8(8), 5869–5878.

Bellen, R.C. van, Dunnington, H.V., Wetzel, R. & Morton, D.M. (1959). Lexique stratigraphique international: Paris, v. III, Asie, Fascicule 10a Iraq, pp. 333.

Farhaduzzaman, M.D. Abdullah, W.H., Aminul Islam, M.D. & Sia, S.G. (2015). Quality assessment of the Permian coals from Dighipara basin, Bangladesh based on proximate, ultimate and microscopic analyses. *Journal of Bangladesh Academy of Sciences*, 39(2), 177-194.

Fouad, S.F. (2015). Tectonic Map of Iraq, Scale 1:1000000, 3rd edition. *Iraqi Bulletin of Geology and Mining*, 11(1): 1- 8.

Jassim, S.Z. & Buday, T. (2006). Late Toarcian – Early Tithonian (Mid-Late Jurassic) Megasequence AP7. Chapter 10 in Jassim, S.Z., and Goff, J. (eds.) *Geology of Iraq*. Dolin, Prague and Moravian Museum, Brno, Czech Republic, pp. 117-123.

Nicholls, G.D. (1968). The geochemistry of coal-bearing strata. In Murchison, D. and Westoll, T.S. (editors). *Coal and coal-bearing strata.* Oliver and Boyd, Edinburgh, pp. 269-307.

Othman, R.S. (1990). *Generation, migration, and maturation of the hydrocarbons, Northern Iraq (Upper Jurassic-Lower Cretaceous).* MSc thesis, University of Salahaddin, Erbil, Iraq, pp. 208.

Parnell, J., Ruffel, A.H., Monson, B. & Mutterlose, J. (1996). Petrography and origin of deposits at the Bentheim bitumen mine, northwestern Germany. *Mineralium Deposita,* 31, Springer–Verlag, pp. 104-112.

Saini, M.K., Srivastava, P.K. & Choudhury, N. (2015). Development of Moisture and Ash Based Correlation for the Estimation of Mineral Matter in High Ash Indian Coal. *International Journal of Clean Coal and Energy*, 4, 33-42

Salae, A.T. (2001). Stratigraphy and Sedimentology of the upper Jurassic succession, Northern Iraq. MSc thesis, University of Baghdad, Baghdad, Iraq, pp. 95.

Thomas, L. (2002). *Coal Geology*. West Sussex, England: John Wiley and Sons Ltd., pp. 384.

Vorres, K.S. (1986). Chemistry of mineral matter and ash in coal, an overview. *ACS Symposium Series, American Chemical Society*. Washington, DC, USA. Retrieved from https://pubs.acs.org/doi/pdf/10.1021/bk-1986-0301.ch001.